Long-duration ionisation effects in beam-driven plasma-wakefield accelerators

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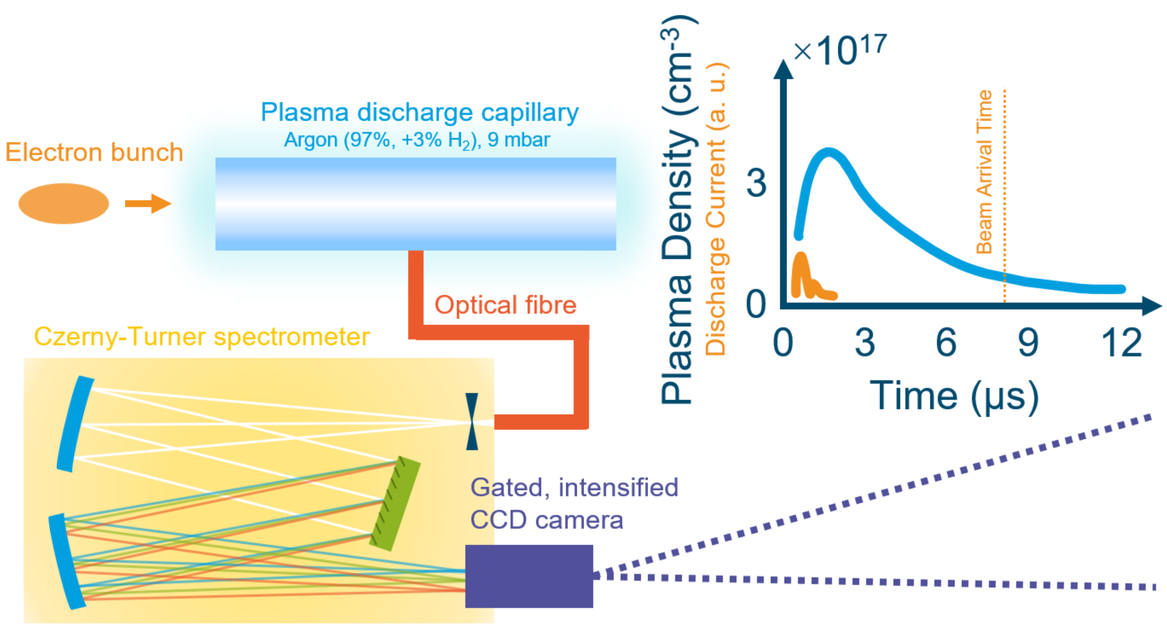
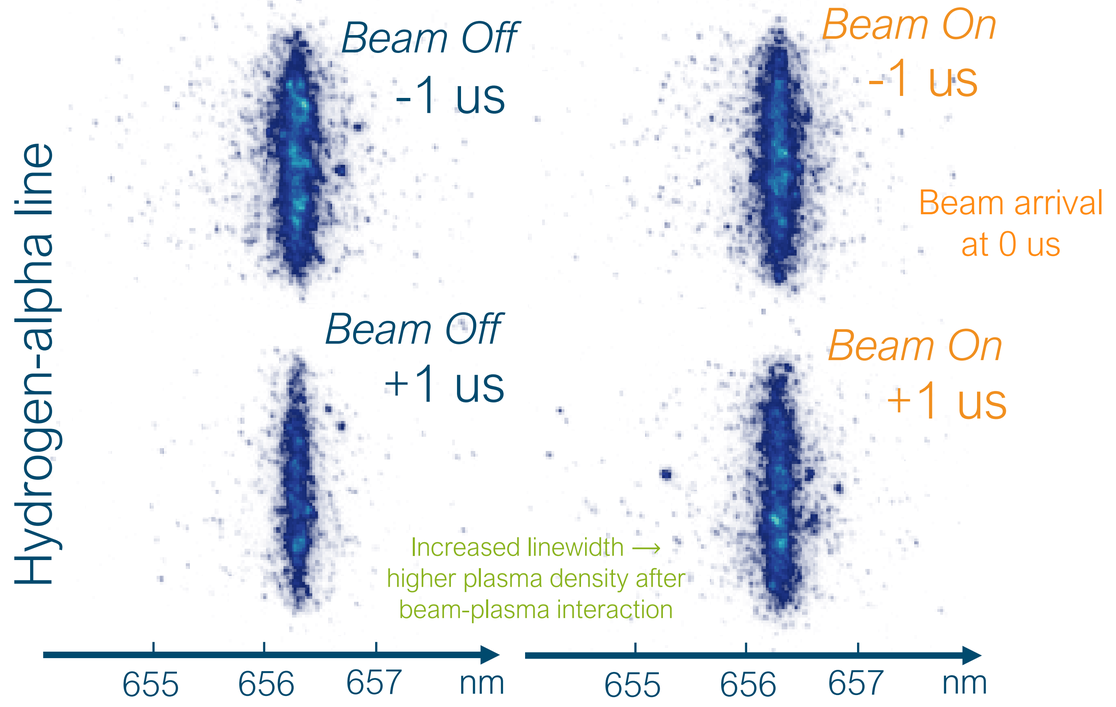
FLASHFORWARD

High-repetition-rate requirements

- Acceleration repetition rate is a factor in collider luminosity and FEL integrated brightness.
- Present and future accelerators operate in O(MHz) burst modes or O(kHz) average frequency.
- Ion motion recovery time of O(100) ns in theory allows for O(10) MHz repetition rate for PWFA[3].
- Investigation needed on managing single-shot thermal effects from deposited energy in plasma.

Facility	Bunch separation within a macro-pulse	Macro-pulse repetition rate	Number of bunches per macro-pulse
HALHF[1]	16 ns	100 Hz	160
FLASH[2]	1000 ns	10 Hz	800

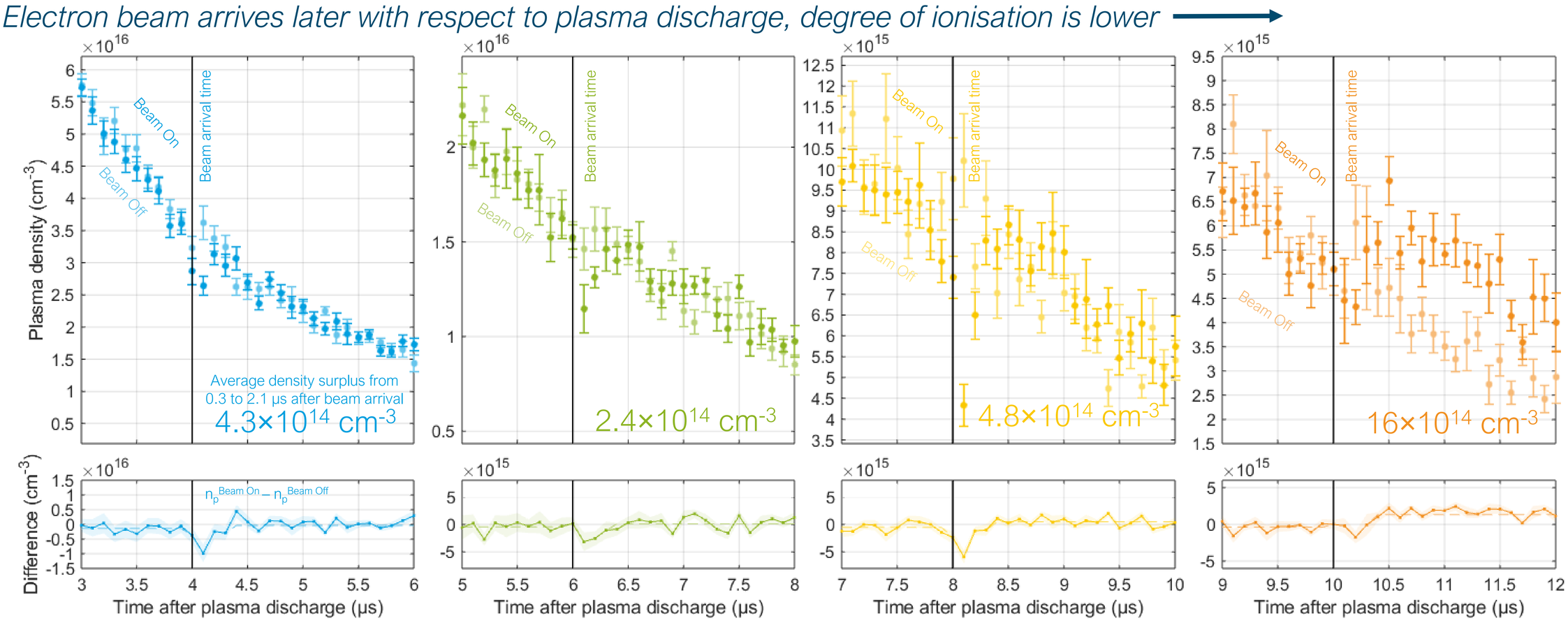




Experiment

- FLASH electron bunch interacts with a plasma in an electrical discharge capillary, containing argon doped with hydrogen.
- Plasma light is transported with a fibre to a spectrometer; images of the H-Alpha line are taken with a gated intensified camera[4].
- The linewidth of the H-Alpha line is used to determine the plasma electron density for a given plasma electron temperature range[4,5].
- Timing scan of the H-Alpha linewidth in the plasma is taken for when there is interaction with the beam ("Beam On") and when there is not ("Beam Off").

Electron beam arrives later with respect to plasma discharge, degree of ionisation is lower ⟶



Result

- *First 300 nanoseconds after beam arrival:* plasma electron heating ⟶ spectral intensity shift away from H-Alpha towards higher wavelengths ⟶ reduced intensity and linewidth of the H-Alpha line.
- *300 nanoseconds after the beam arrival:* H-Alpha recovers its linewidth, it increases, and a higher plasma density is observed for the "Beam On" case.
- Ions are contributing to the impact ionisation of the neutral atoms on nanosecond timescale[6]; they thermalise O(100) ns for temperatures of few eV and densities of 10^{16} cm^{-3}[7]
- Duration ≥ 2 μs for the latest beam arrival time; for earlier beam arrival times, this effect is largely reduced.

Discussion

- Energy deposited in plasma by the electron beam results in an ionisation effect over a microsecond timescale: after wakefield dissipation, hot electrons and ions impact ionise neutral atoms in the plasma over hundreds of nanoseconds.
- For higher initial degrees of ionisation in plasma, this effect can be reduced; otherwise, it precludes a plasma recovery in O(100) ns.
- Such ionisation may act as a source of replenishing plasma density as it is decaying and cooling.
- Further investigations using the electron probe bunch, other initial gas densities, and gas species are planned to be explored at FLASHForward.

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7th EAAC
21-26 September 2025, Isola d'Elba, Italy

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